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# Fabric Filtration with Integral Particle Charging and Collection in a Combined Electric and Flow Field. Part 1. Background Experimental Work, Analysis of Data, and Approach to the Development of a Mathematical Engineering Design Model

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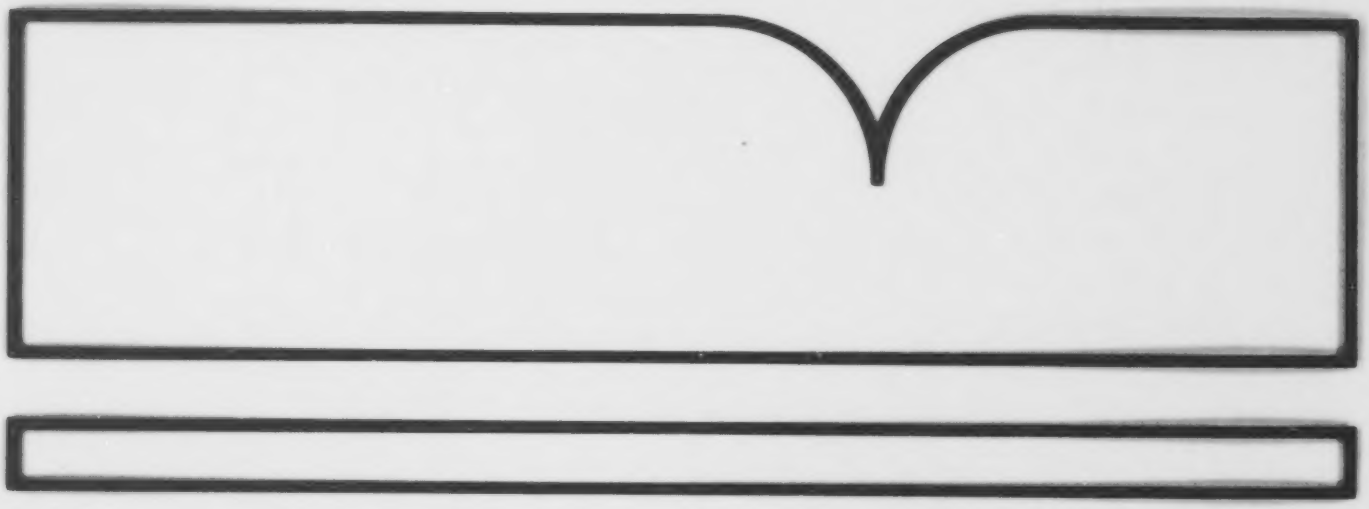

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16. ABSTRACT The paper discusses a system of integral particle charging and collection in a combined electric and flow field that has been developed to provide pressure drop reductions that are larger than previously reported in electrified fabric filtration. A mathematical model has been developed that predicts the nonuniform deposition that results and the relative pressure drop as compared to conventional nonelectrified filtration. The paper gives the background in applying electrostatics to fabric filtration. It discusses the technique for integral particle charging and collection in a combined electrical field. It describes an experimental program that would provide the data needed to prepare a mathematical engineering design model. Measurements of areal density, drag, thickness, and dust cake bulk density were made upon particle layers deposited on fabric filters with integral particle charging and collection with a combined electric and flow field. Application of charging resulted in a nonuniform deposition, with areal density, thickness, and drag decreasing from the inlet to the top of the bag. No consistent relationship was found between drag and dust cake bulk density. Local changes in the electrical conditions, such as nonuniform corona, caused discontinuities in the dust layer.

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# FABRIC FILTRATION WITH INTEGRAL PARTICLE CHARGING AND COLLECTION IN A COMBINED ELECTRIC AND FLOW FIELD

## PART I. BACKGROUND, EXPERIMENTAL WORK, ANALYSIS OF DATA, AND APPROACH TO THE DEVELOPMENT OF A MATHEMATICAL ENGINEERING DESIGN MODEL

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### Summary

The application of electrostatics to fabric filtration improves performance by decreasing the pressure drop across the collected dust layer. Electrostatics is applied by precharging the particles, or collecting the particles in an electric field, or a combination of both. A system of integral particle charging and collection in a combined electric and flow field has been developed which provides pressure drop reductions that are larger than previously reported in electrified fabric filtration. A mathematical model has been developed that predicts the non-uniform deposition that results and the relative pressure drop as compared to conventional (non-electrified) filtration. This work is reported in two parts. This part presents the background in the application of electrostatics to fabric filtration. The technique for integral particle charging and collection in a combined electrical field is discussed. An experimental program is described that would provide the data needed to prepare a mathematical engineering design model. Measurements of areal density, drag, thickness, and dust cake bulk density were made upon particle layers deposited on fabric filters with integral particle charging and collection with a combined electric and flow field. The application of charging resulted in a non-uniform deposition, with areal density, thickness, and drag decreasing from the inlet to the top of the bag. No consistent relationship was found between drag and dust cake bulk density. Local changes in the electrical conditions, such as non-uniform corona, caused discontinuities in the dust layer.

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### 1. Introduction

The work reported here is the development of an engineering design methodology and mathematical predictive performance model for fabric filtration with integral particle charging and collection in a combined electric and flow field. This technology, using applied electrostatics, will allow operation of fabric filtration baghouses at reduced pressure drop, with less fan power, or with

less bags at the same fan power. The mathematical model at this stage of the technology development, will allow an engineering design to be made with a reasonable degree of certainty.

The work is presented in two parts: (1) Background, experimental work, analysis of data, and approach to the development of a mathematical engineering design model; and (2) development and verification of the mathematical engineering design model.

## 2. Fabric filtration

Fabric filtration is one of the principal technologies for the removal of particle matter from gas streams. Other technologies include electrostatic precipitators, scrubbers, inertial devices, and filtration by non-fabric media. Fabric filtration has been described as the use of a textile fabric to separate particles from a gas passing unidirectionally through the fabric. The particles (or dust) are retained upon the fabric, while the cleaned gas continues on and is ultimately discharged [1]. The term fabric filter implies the use of a textile fabric as the filter media composed of many individual fibers organized into a planar sheet. This planar sheet has measurable, semipermanent properties that allow it to be engineered into well defined shapes such as bags or envelopes independent of any support structure or enclosure.

The specific interest in this work is the application of fabric filtration to the cleaning of high volume gases from steam-electric utilities and other industries. For these applications the fabric is set up in the form of bags. Gas flow is arranged so that it flows either from inside-to-outside of the bags or in the opposite direction, from outside-to-inside. The dust is collected on either the inside or the outside of the bag, depending on the direction of flow.

Fabric filtration in the form of baghouses has been used for many years for various industries. In recent years, in response to increasingly more stringent air pollution control requirements, baghouses have gained more prominence, especially in the electric power industry. The majority of electric power plants use baghouses with inside-to-outside flow. In the United States in 1984 there were over 110 baghouses associated with more than 20,000 MW of electric generating capacity [2]. Electrostatic precipitators (ESPs) are used in the majority of the other plants, but interest in baghouses for electric utility application is increasing. Inside-to-outside flow is also used for large high volume gas flow applications in other industries.

For inside-to-outside flow fabric filtration bags, woven fabrics are typically used. These fabrics are made on looms by processes well known in the textile industry. Woven fabrics have pores that are large in comparison to the size of the particulate matter or dust that is to be filtered. Their filtering action depends on the building up of a dust cake on the surface of the fabric, which actually performs the filtration. The aerodynamic resistance of this filtration

medium usually requires a relatively low gas flow through the fabric to keep fan power requirements within reasonable limits. However, it performs well in filtration of gases having a high dust load.

To make a practical filtration system, some means must be introduced for cleaning the accumulated dust from the bags to maintain the pressure drop within the fan operating limits. For the inside-to-outside flow method this cleaning is done by either reversing the gas flow, mechanical shaking, or some combination of both.

Filtration is a continuing process of dust accumulation and cleaning, followed by another period of dust accumulation. The bag is not cleaned to bare fabric. It maintains a residual dust cake which tends to increase slowly over a long period of time during the life of the bag, which is about 2 to 5 years [2]. When the pressure drop from this residual cake becomes too high, it is necessary to rebag the baghouse. Various techniques, such as use of high-intensity sonic energy, have recently been used to slow down the rise in pressure caused by the residual dust.

A major consideration is the maximum increase in pressure drop, as the dust cake builds up. If this pressure drop can be minimized, there would be a significant fan power savings, estimated to be about $50,000 per year for each 250 Pa [2]. Another aspect of this filtration cycle pressure drop is the limit on gas flow. If the pressure drop could be reduced, the allowable gas flow could be increased.

Reviewing the data that have been reported on electric power industry baghouses [2] suggests that the gas flow with inside-to-out reverse flow cleaning (which the majority are) is about 0.01 $m^3/s\ m^2$. For a full-size utility bag 9 to 10 m long [3], with a diameter of 0.3 m, flow through each bag would be limited to about 6 $m^3/min$. The gas flow from a 500 MW electric generating capacity plant, assuming a reasonable gas rate of 100 $m^3/min$ per MW of electric generating capacity, would require about 8000 bags. Reducing the number of bags could be the basis for a worthwhile capital saving.

Considerable work has been done on limiting the pressure drop rise during the filtration cycle. Much of the work has been related to making engineering changes to the fabric, and improving the flow distribution and uniformity in the baghouse. The last facet on flow distribution is similar to work on flow distribution to help improve the performance of ESPs.

### 3. Application of electrostatics to fabric filtration

A large amount of research and development has been done on the application of electrostatics [4]. It has long been recognized that electrostatic charges and forces play a role in fabric filtration [5]. It has been claimed that the effects of electrostatics, mainly in the triboelectric properties of dusts and fabrics, are very important, if not critical, in controlling filtration properties [6].

To better understand the role of electrostatics in fabric filtration and how it might improve performance prediction and engineering of the process, and to take advantage of the effects to improve performance, a number of workers investigated the phenomena. The work can be broken down into several areas:
— Charging of particles prior to collection;
— Collection of particles in an electric field;
— Combined particle charging and collection.

Much of the work has been involved with single- and multiple-particle/single-fiber collection. The work on single-fiber capture in an electric field has, of course, added to the knowledge of particle/fiber interactions, which has been part of classical filtration analysis for some time. This work has shown, as perhaps no other work has, the potential effects of applying electrostatics to particle capture. The capture of particles by long thin chain dendrites in an electric field is striking. In the absence of an electric field, the particles may also form dendrites; however, they are short and multibranched [7–9].

For fabrics, a number of workers charged the incoming particle matter prior to deposition on the porous fabric media. This was usually done by an upstream corona charger. The work ranged in size from small laboratory patch filters, through laboratory baghouses, to field pilot tests.

The pressure drop reduction from particle charging was found to be humidity sensitive with the greatest effect occurring under a low humidity condition which causes a surface charge buildup. Reduction in pressure drop also occurred from collection of some of the particulate matter by the charger [10–15].

Other workers applied an electric field, without charging of the dust particles, to the filtration process. The electric fields were either parallel to the gas flow [16,17] or perpendicular to the gas flow [18,19]. Impressive claims were made for each of the two electric field directions.

Recent significant work has made use of electric fields perpendicular to the flow. This concept which is called electrostatically stimulated fabric filtration (ESFF) has been developed under the auspices of the United States Environmental Protection Agency. The ESFF concept makes use of electrodes which are placed in the axial direction, parallel to each other on about 20 mm centers. Electric fields of about 200–800 kV/m between adjacent electrodes are used; operation is below corona onset voltage. The various electrode arrangements that were used were either in a harness, that was wrapped around a bag, or stitched or woven into the fabric.

The work on ESFF has ranged from small laboratory baghouses, operating at temperatures up to 150°C, to fairly substantial field pilot units [3,20–22]. Pressure drop reductions were usually about 40 to 50%.

Various workers in the field have attempted to introduce charged particles into a fabric filter bag having an electric field in the collection zone. Some of the work [23] clearly showed the effects of operation with and without charging and with various collector voltages in respect to reduction of particle pen-

etration. Other work [24], which also used an upstream precharger, clearly showed a decreased pressure drop. It also gave evidence of non-uniform deposition in a flow field in which the charged particles were simultaneously introduced into an electric field. Still other work [25,26] had the precharger closely coupled to the bag by placing it at the inlet. It also demonstrated that a non-uniform dust deposit would result.

### 4. Fabric filtration with integral particle charging and collection in a combined electric and flow field

A system for providing integral particle charging and collection in a combined electric and flow field was suggested as shown in Fig. 1 [27]. In this system, sometimes called Advanced ESFF (AESFF), the corona discharge wire is axially located within the fabric bag, and the electric field is developed between the corona discharge wire and the bag. The bag is made conductive by including conductive yarns in the fabric during the weaving process. Alternatively, if the particulate matter is low in resistivity, it could make the bag sufficiently conductive. The generation of corona for charging and development of the electric field requires only one power supply. Except for its porous walls, the device is similar to a wire–pipe ESP.

The system was tried at small scale in a laboratory single-bag experimental baghouse at the U.S. Environmental Protection Agency's Air and Energy Engineering Research Laboratory at Research Triangle Park, North Carolina. It was observed that there was a non-uniform deposition which resulted in a reduced pressure drop over that of both conventional filtration and ESFF. It was found that pressure drops of 10 to 30% of that of conventional fabric filtration were achieved [27].

A decision was made to proceed with a field pilot plant evaluation. The pilot unit contained six bags, each 7.3 m long and 0.2 m in diameter. The boiler, from which the slipstream was taken, was a spreader stoker type which typically has a large amount of unburned carbon in the fly ash. Preliminary measurements indicated that the resistivity was $1 \times 10^5\ \Omega$m or less. This resistivity was considered sufficiently low so that three of the six bags, which were Teflon B® coated filberglass, had no provisions to increase their conductivity. The other three bags had stainless steel yarn woven into them in the longitudinal (axial) direction. After 4 months of tests it was found that it was possible to operate at a pressure drop that was only 20 to 30% of that of conventional filtration. It was also shown that, for a low-resistivity dust, there was no difference in performance between the non-conductive bag, which depended on particle matter conductivity, and the bags that had conductive yarn woven into them [28,29].

A second pilot evaluation was undertaken with integral particle charging and electric field at the EPA pilot baghouse at Southwestern Public Service

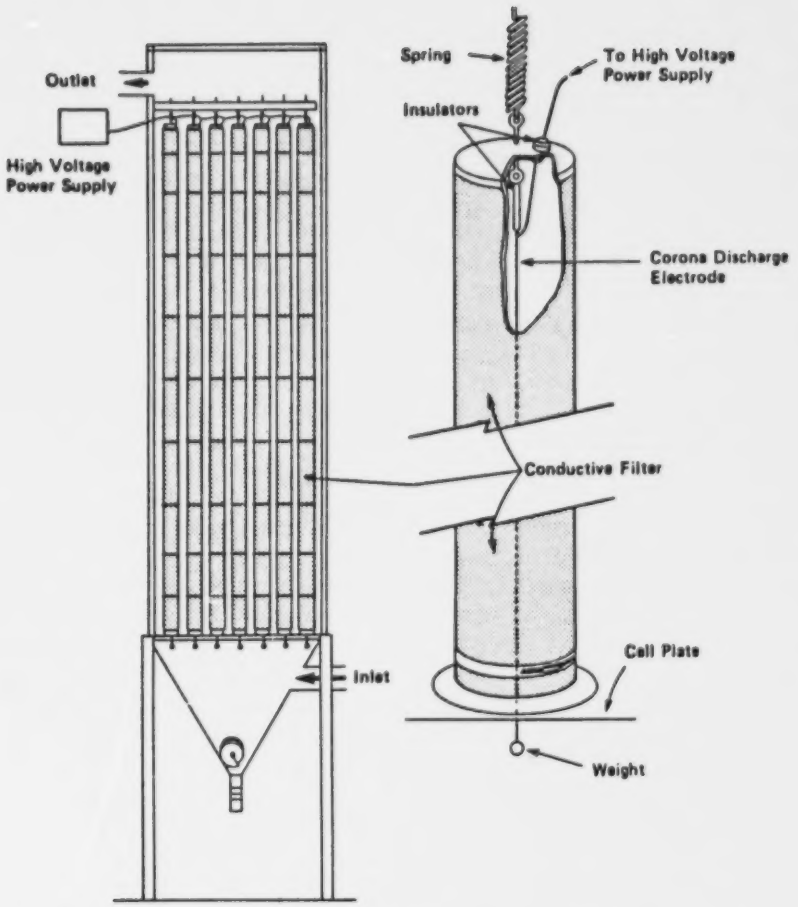


Fig. 1. Fabric filtration with integral particle charging and collection in a combined electric and flow field.

where some of the earlier ESFF field pilot work had been done. The fly ash, from a pulverized-coal-fired boiler, had a considerably higher electrical resistivity than did the spreader-stoker fly ash. The bags that were used had woven-in stainless steel yarns, connected electrically to ground [30]. It was found that, when the bags were clean, a high pressure drop reduction was achieved. It was also found here that the electrified bags cleaned better than did conventional bags. However, there were problems with the reverse-air cleaning system: because the bags were not being cleaned sufficiently, the residual pressure

drop continued to rise until it dominated the performance. This happened with both the electrified and conventional bags.

## 5. Experimental program

A single-bag experimental baghouse at the EPA laboratory facilities was set up as shown in Fig. 2. The device is in a thermally insulated metal shell. Dirty-particle-bearing gas is introduced through the hopper and flows up into the bag, with the particulate matter deposited on the inner surface. The cleaned gas flows through the fabric and out of the baghouse (inside-out filtration).

A program was established to develop data for the preparation of a mathematical engineering design model for fabric filtration with integral particle charging and collection in a combined electric and flow field [31].

The single baghouse can operate at tempertures ranging from ambient to 200°C. The gas flows in a closed loop. A portion of the gas is vented to allow

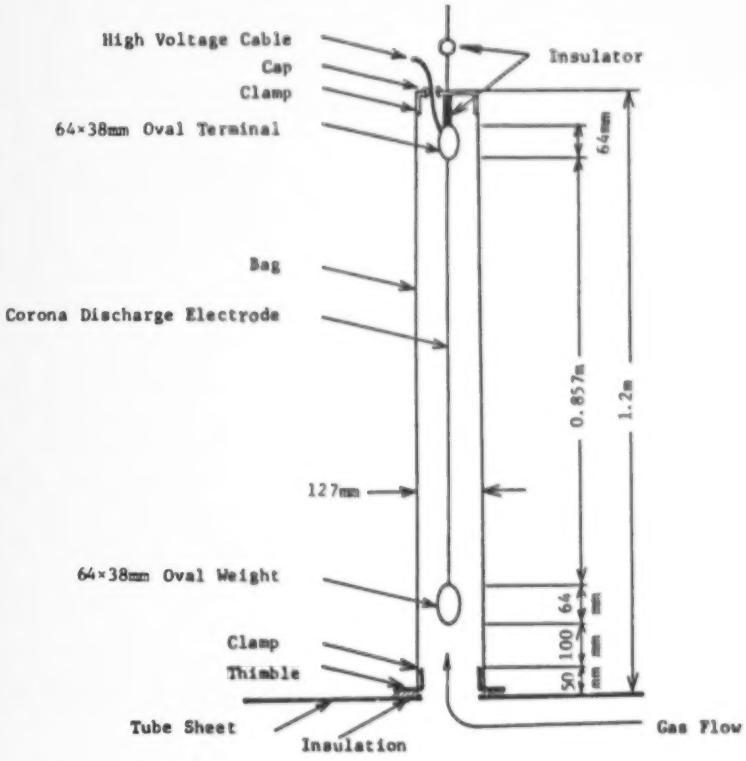


Fig. 2. Single-bag electrified fabric filtration setup.

maintaining negative pressure. A calibrated orifice plate senses the gas flow; a differential pressure cell across the orifice plate provides a signal used to maintain constant flow. Particle matter is aspirated into the unit with the make-up air to redisperse the dust. A screw feeder, calibrated prior to each test, meters the particle matter. At elevated temperatures the moisture content of the gas is modified by adding steam to the unit. This experimental baghouse has many of the operating features and hardware of full-scale equipment including a built-in reverse-air and shake-cleaning mechanism.

The fabric used for the filter bags was J.P. Stevens 648, a 570 $g/m^2$ fiberglass cloth coated with 10% Teflon B®. This is a typical filtration fabric for reverse-air filtration. Some tests used the fabric in standard filtration form, with unmodified electrical conductivity. The electrical conductivity of these fabrics depended mainly on that of the materials plus the particulate matter that coats them when used. Other tests used a bag of the same material, except that the conductivity had been modified by having stainless steel yarns woven into the fabric. The yarns, running axially on 20 mm centers, each consist of 90 fibers of 316L stainless steel of 22 $\mu$m diameter. The same bags were used over and over again for the various tests.

The bags were clamped on the bottom to the thimble, and on the top to the cap. The bags were tensioned sufficiently to prevent sagging. The thimble was insulated from the tube sheet, which allowed it to be used, along with the bottom bag clamp, as the current return point to ground. The actual return to ground was through a current meter with external protective circuitry to guard against possible damage from sparking in the baghouse.

The oval weight at the bottom of the corona wire, and the terminal at the top minimized corona current going to the thimble and cap, which could cause erroneous current meter readings. The weight at the bottom also minimizes swinging, especially if sparking occurs.

The bags could be opened along the seam to allow removal from the baghouse and placement on a flat surface for examination and testing of the dust cakes that were deposited. The bags without the woven-in stainless steel yarns had a plastic zipper installed on the seam to simplify removal. The zipper was plastic instead of metal to avoid distorting the electric field in the bag. The use of plastic limited the temperature to 82°C. After installation it was necessary to apply tape over the zipper to prevent gas leakage. The bag that already had metal conductors in the fabric was closed with metal clips, normally used in an office for holding papers together. All of the clips were connected through the metering circuit to ground. The particulate matter that was used had been obtained, after collection in a baghouse, at the Harrington Power Station of Southwestern Public Company (SWPS), Amarillo, TX.

The size distribution of the undispersed SWPS fly ash was determined by outfitting a bag with an MRI Model 1502 inertial cascade impactor inserted at mid-height. Under isokinetic sampling conditions, the mass geometric mean

diameter was 3.3 $\mu$m, and the geometric standard deviation was 2.9. The charge-to-mass ratio of the redispersed SWPS fly ash was measured using this same test bag. On a total basis the fly ash was found to be almost electrically neutral.

The baghouse arrangement, shown in Fig. 2, was used to determine the effects of varying voltage, current, resistivity, temperature, and gas flow. Voltage was varied by changing the setting of the DC power supply. The voltages applied to the corona discharge wire were negative and ranged from 23 to 50 kV. The current was varied somewhat by changing the diameter of the corona discharge wire for different tests — sizes were 2.4, 3.2, 6.4, and 12.7 mm. Resistivity of the SWPS fly ash was changed by varying temperature and moisture. Negative corona was used because of the tendency of positively energized ESP devices to spark at lower voltage. This is the reason that negative polarity for the corona is used almost exclusively in modern ESPs [32]. The temperatures were 21, 82, and 149°C. A temperature of 149°C is similar to that of many coal-fired steam-electric power plants. Moisture levels were varied from about 1% to slightly more than 9%. Moisture levels of 6 to 9% are the range in which most coal-fired boiler gases operate [32].

After each test the bag would be carefully removed from the baghouse, to minimize damage to the dust cake. The dust cake from an electrified test run was invariably more fragile than that from a non-electrified test run. Portions of the dust cake often fell off during removal. Sagging of the bag would cause cracks in the dust cake which would cause an erroneous permeability measurement at that point. Permeability was measured with a specially constructed device based on a standard test method for air permeability of textile fabrics [33], modified by decreasing its size to increase the resolution and thereby allowing tests to be made on smaller areas.

The areal density of the dust cake in kilograms per square meter was measured by vacuuming a known area of dust cake onto a filter paper, which was weighed both before and after. The area for vacuuming was established by the use of a mask, 25 × 25 mm, placed on the dust cake.

The dust cake thickness was determined by two methods. The first used a greased slide inserted into the dust cake; the dust on the greased slide was measured with calipers. The second used feeler gauges to judge the height of a freshly exposed edge of the dust cake. The reported measurement was an average of the two.

All measurements were made near the midpoint of the opened fabric bag to minimize possible distortions caused by electrical effects, leakage, and handling at the seam.

After each test the bags were thoroughly vacuumed. Several measurements were made of the drag of the clean bags. Drag, which is the resistance to flow, is defined as the ratio of the pressure drop to face velocity. The average clean bag drag was 660 Pa/(m/s). Each bag was cleaned thoroughly prior to a test to enable it to be returned to a reproducible condition at the start of the next

test. In this respect the tests did not represent actual industrial practice in which the bags are cleaned, from time to time, to some residual drag as discussed earlier. Reproducing this residual drag would have been extremely difficult and impractical.

## 6. Experimental results

A number of tests were performed in the single bag unit shown in Fig. 2 [31]. Figures 3 through 6 show the drag, areal density, thickness, and dust cake bulk density as a function of position under the corona discharge electrode for differing electrical conditions. The active portion of the dust cake under the corona discharge wire is the only part that is of interest. The end conditions would be expected to change with different mechanical designs. In addition, these test bags were very small in comparison to full-size, electric utility bags which are typically 9 m or more in length, and 0.3 m in diameter [3].

Drag is the resistance of the flow of gas through the filtration medium. It is defined as:

$$S = \Delta P / v_f \tag{1}$$

where: $\Delta P$ = pressure drop across the fabric (Pa), and $v_f$ = face velocity of the gas (m/s). The quantity $v_f$ is in terms of volumetric flow per unit of fabric area, $(m^3/s)/m^2$, which becomes m/s. In filtration, drag is analogous to electrical resistance [34]. Drag is determined by use of the permeability apparatus previously described which actually measures $v_f$ at a desired pressure; drag is the reciprocal of the face velocity per unit of pressure drop. The average $v_f$, when applied to a whole baghouse, is called the gas-to-cloth ratio. This gas-to-cloth ratio is used for baghouses similarly to the use of specific collector area (SCA) for electrostatic precipitators.

The drag was determined by using eqn. (1) at 16 equally spaced sites under the wire. Each face velocity measurement was taken at three different pressures — 125, 250, and 500 Pa — and averaged for each site. For some tests the drag taken at the lowest pressure could not be used, especially for high drags because the rotometer would give a poor indication with the low flow. The areal density and thickness were measured at 13 evenly spaced points. The cake dust density was calculated from the two independently measured values of areal density and thickness.

Finally, measurements were made on the dust cake deposited during normal filtration means (no electric field). The results are presented in Table 1. The drag, thickness, and areal density were quite uniform along the length of the bag. The dust cakes for the non-electrified bags were smooth and even; there was less tendency for these dust cakes to dislodge themselves from the bag, which suggests that conventional filtration bags would not clean as well. The corollary is that the electrified bags appear to clean more easily. This was seen

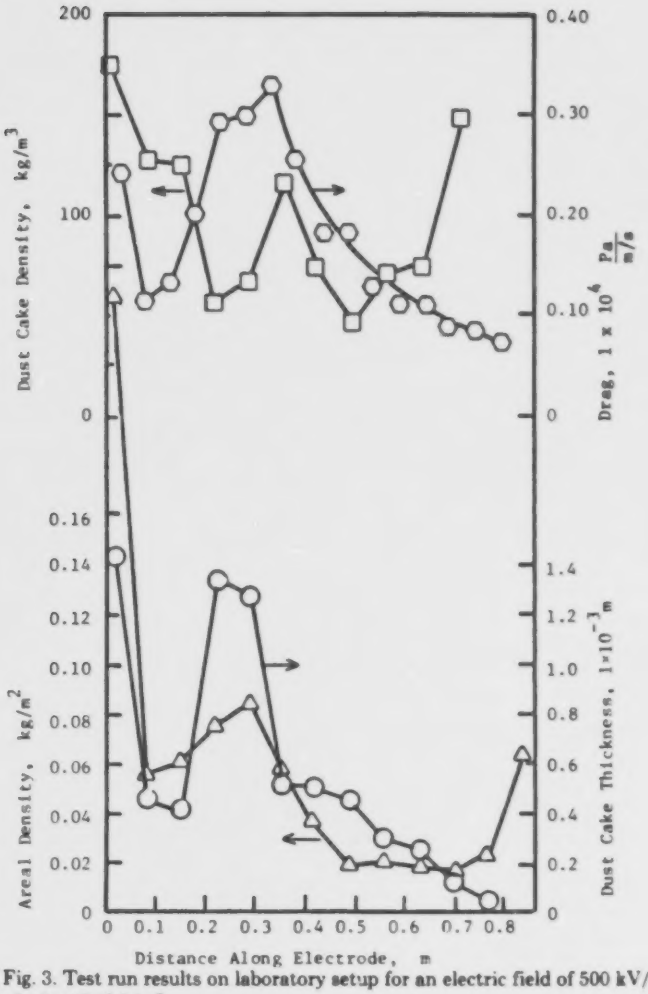


Fig. 3. Test run results on laboratory setup for an electric field of 500 kV/m and current density of $4.5 \times 10^{-4}$ A/m$^2$.

at the pilot units using fabric filtration with integral particle charging and collection in a combined electric and flow field [29,30].

## 7. Analysis of data

Results of the single-bag tests for fabric filtration, with integral particle charging and collecting in a combined electrical and flow field, indicated a

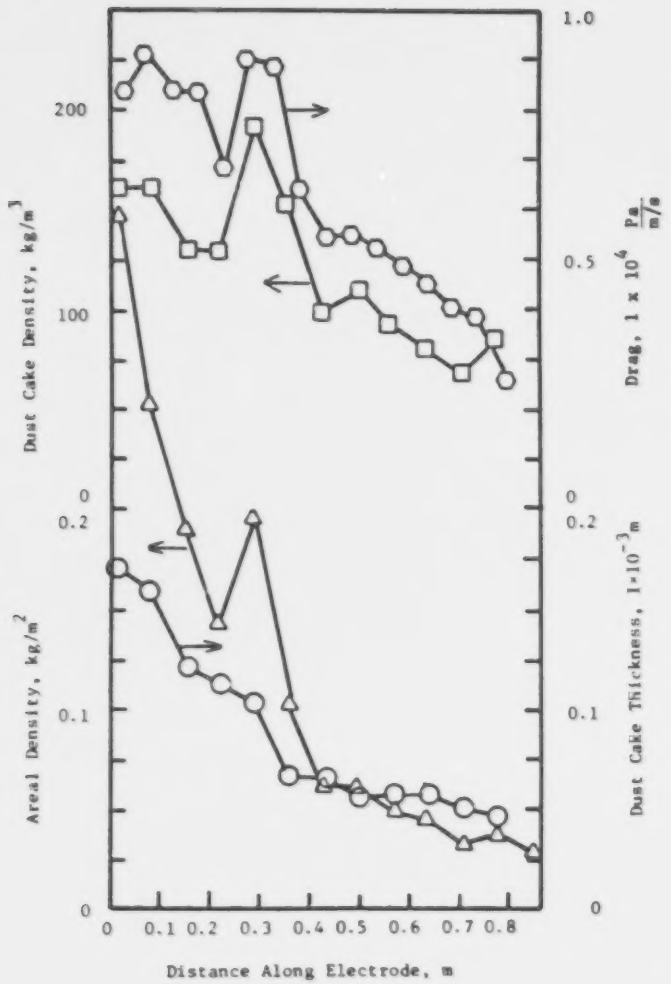


Fig. 4. Test run results on laboratory setup for an electric field of 780 kV/m and current density of $6 \times 10^{-5}$ A/m$^2$.

number of preliminary conclusions:

(1) Integral particle charging and collection in a combined electric and flow field in a baghouse fabric filtration unit will provide a lower dust cake drag than will conventional baghouse filtration.

(2) The application of charging current with electric field results in a non-uniform dust cake deposition with the heaviest deposition of particle matter at the inlet (bottom) of the bag.

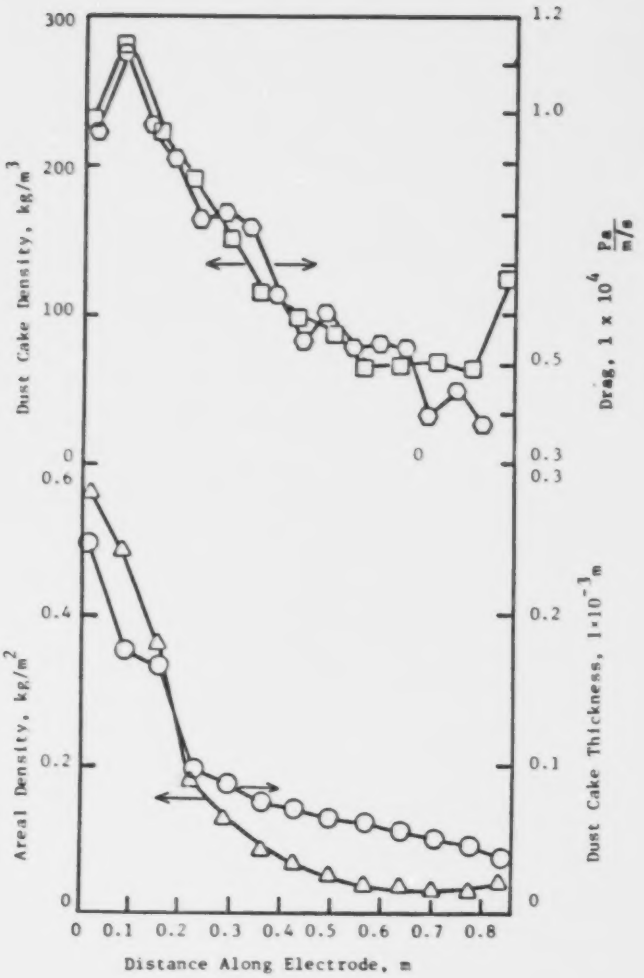


Fig. 5. Test run results on laboratory setup for an electric field of 750 kV/m and a current density of $3 \times 10^{-5}$ A/m$^2$.

(3) The drag decreases with decreasing areal density and dust cake thickness with the least at the top of the bag — the point farthest from the inlet.
(4) There is no correlation between dust cake bulk density and drag.
(5) Local differences in the non-uniform dust deposit have been observed: many are clearly linked to uneven corona current distribution.

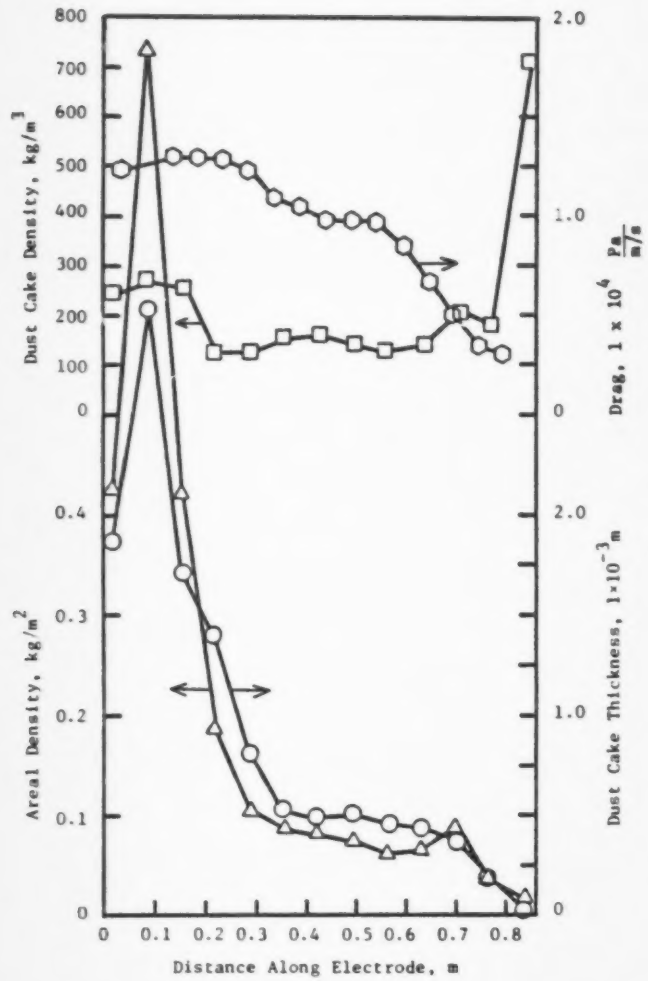


Fig. 6. Test run results on laboratory setup for an electric field of 630 kV/m and a current density of $1 \times 10^{-5}$ A/m$^2$.

(6) The dust cake that forms with integral particle charging and collection in a combined electric and flow field is more fragile, dislodges more easily from the fabric, and is more easily damaged than the dust cake formed in conventional filtration.

Several of the above preliminary conclusions are obvious. Others are less obvious and require further explanation and discussion.

TABLE 1

Conventional filtration dust layer properties

| Property | Temperature 21°C (~1% $H_2O$) | Temperature 82°C (~8% $H_2O$) |
|---|---|---|
| Dust feed, g/min | 7.72 | 8.66 |
| Gas/cloth, m/s | 0.02 | 0.02 |
| Average drag, $10^4$ Pa/(m/s) | 1.78 | 1.64 |
| Average thickness, mm | 0.64 | 0.88 |
| Average areal density, kg/m$^2$ | 0.38 | 0.41 |
| Average dust cake density, kg/m$^3$ | 590 | 530 |

The dust cake bulk density appears to change as a result of the application of charging and electric field. However, it is difficult to generalize on the change; the relationship of dust cake density and decrease in drag is ambiguous and somewhat inconsistent. For many of the tests the dust cake density does decrease at the same time that the drag decreases. In other tests the dust cake density shows a rising trend (or at least stays constant over some portion of the cake) while the drag is decreasing.

In all tests there is a trend for the drag to decrease along with the areal density. This suggests that there is not a significant change in the characteristics of a dust cake deposited non-uniformly along a bag with integral particle charging and collection in a combined electric and flow field. Therefore, it appears that the non-uniform deposition plays the dominant role in the drag reduction.

The decrease in drag with respect to a decrease in dust cake areal density and thickness is apparent and conclusive from examining the multiplicity of test runs. For most of the tests in which there were electric field and average current densities greater than about $1 \times 10^{-5}$ A/m$^2$, average drag for the filtration was less than for conventional filtration.

For a number of tests, dust points built up on the corona wire. The dust points were as high as 0.3 to 0.5 cm. These dust points were usually just above the bottom weight, but not always. The presence of such points suggests that the corona currents in that area were heavier than the average. These points would probably form quite early in the filtration cycle when a particle of dust, containing a positive charge, would be attracted to the otherwise clean wire and a corona tuft would form. Tufts on the corona wire are a characteristic of negative corona [32]. The high current under the tuft would cause back corona which would expel positively charged particles that would tend to follow the field lines that converge onto the tuft and, thereby, contribute to the dust point.

The high local currents, which occurred in the region just above the lower

weight, were seen on the opened bags as rough uneven layers containing craters, bare spots, and in areas in which back corona had formed by blowing the dust off the fabric. Similar deposition had been noted by others [12]. The results can be seen in the test results, Figs. 3 through 6, as discontinuities in the various traces, especially at the bottom of the bag. Discontinuities were especially apparent for test runs in which the current density was high. Other discontinuities that are seen in some of the test results are probably also related to non-uniform corona current distribution. A local electrical condition that forms in one part of a bag, that reduces the drag significantly, will cause more gas to flow to that area because of the effect of placing a lowered flow resistance in parallel with higher ones. The remainder of the bag would receive less gas and less particulate matter. This is believed to be a contributing reason for some trace runs, in which there were heavy currents at the bottom of the bag with resulting large discontinuities, to have relatively little dust deposited at the top.

If a local electrical condition has formed, the remnants (e.g., rough uneven spots, craters) will be removed from the bag during the next cleaning cycle. However, if the condition that caused it (e.g., a dust point) remains on the corona wire, then it will likely start again in the next filtration cycle. Therefore, cleaning the corona wire, similar to what is done in an electrostatic precipitator, should be included in a practical system. Corona wire cleaning was not used in either of the pilot units previously described. Finally, a microprocessor controller or perhaps pulse energization should be considered for use in baghouses using integral particle charging and collection in a combined electric and flow field.

Back corona has been mentioned as having been observed. Its presence is indicated by corona current that is very erratic and which can be reduced only by lowering the voltage. In some cases it had been noted that the dust cake was blown off the fabric in areas of high current density which is analogous to crater formation on ESP collector plates caused by back corona. In a wire–pipe electrode geometry, the $V$–$I$ curve is significantly steeper than for a wire–duct geometry. This has been observed by the author and others [35]. This steepness in the $V$–$I$ characteristics makes control of current more sensitive than for the wire–duct geometry used in conventional ESPs. In an ESP, hysteresis in the $V$–$I$ data is often used to determine the presence of back corona. The sensitivity of changes to the current with small changes in the voltage for this geometry made hysteresis difficult to identify. Milder back corona might be contributing to the dust cake characteristics that have been observed. The bipolar ionic current probe [36], if adaptable to this axial wire fabric filter, could be very useful for studying the effects of the dust cake and its contribution to performance. In an ESP the dust is collected on an electrically conductive plate. The electric field, under the influence of a corona current, is perpendicular to the thickness of the dust layer and is equal to $J\rho$, in which $J$

is the current density and $\rho$ is the resistivity. In the electrified baghouse, a field in the dust cake is perpendicular to the thickness but also parallel to the layer. In the bag without the woven-in conductive yarn, the field is in the axial or longitudinal direction. In bags with the woven-in conductive yarns, the electric field is in the circumferential direction with the conductive yarn forming one boundary. A bag that was sufficiently conductive would not have a field parallel to the dust layer. For the poorly conductive bags, other tests had indicated the presence of high surface charge when the center wire was in corona [31].

In many tests in which dust had been blown off the fabric, dust balls had formed on the conductive yarn [31]. It is assumed that most of the current was terminating on the conductive yarns, even with the dust balls present. This suggests that the dust by itself does not cause back corona, but that the dust/fabric combination does.

Unfortunately, the tests were not sufficiently explicit to define good operating regimes of particle or dust and fabric resistivity.

It has been suggested [37] that a particle resistivity of $1\times10^3$ Ωm would, for all intents and purposes, cause a fabric to act as a ground plane. For a dust resistivity of $1\times10^5$ Ωm there was no discernible difference in performance between unmodified fabrics and fabrics modified by use of a woven-in conductive yarn [29].

For applications in which the dust resistivity is high ($<1\times10^8$ Ωm), it can only be suggested at this time that the fabric resistivity be decreased by incorporation of a metallic or other similarly conductive yarn.

There was significant evidence in a number of the test runs that portions of the dust layer would detach themselves from the porous filter and fall into the hopper; this was often in the form of avalanches. This loss of dust from the layer would tend to decrease the pressure drop. However, the effect cannot be currently quantified.

## 8. Conclusion

The application of electrostatics to fabric filtration in the form of particle charging and electric field improves performance by decreasing the pressure drop across the collected dust layer. A system was described for integral particle charging and collection in a combined electric and flow field.

An experimental test program was developed to provide data to develop a mathematical model to predict performance of fabric filtration with the system of integral particle charging and collection in a combined electric and flow field.

The experimental test program has shown that the application to fabric filtration of integral particle charging and collection in a combined electric and flow field results in a non-uniform deposition. If the fabric is in the form of a bag with inside-to-outside flow, the maximum deposition is at the open end,

and the minimum is at the closed end. The dust deposition pattern is dramatically modified by the application of electrostatics.

The drag or resistance to flow decreases with decreasing areal density and dust layer thickness. The dust cake density does not show any correlation with drag.

Local changes in the electrical conditions (non-uniform corona, back corona) cause discontinuities in the dust layer. These local changes in electrical conditions might not be as significant in large-scale bags as in the small test bags.

Except for low-resistivity particle matter, conductive fabrics would be useful for fabric filtration with integral particle charging and collection in a combined electric and flow field.

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